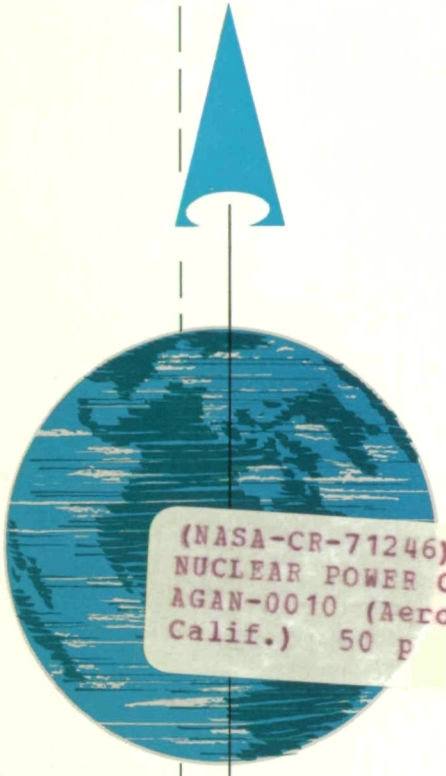
~~CONFIDENTIAL~~

CCN



MODEL SPECIFICATION

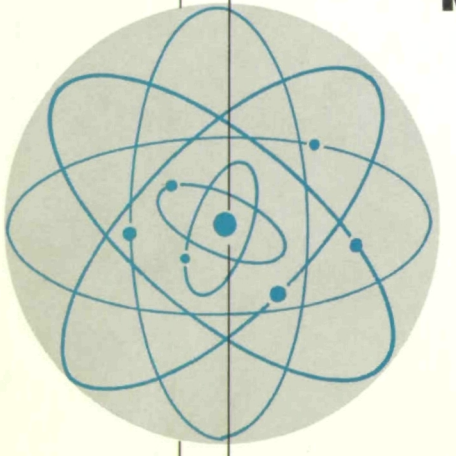
AGC-10054A

~~X66 81429~~
(ACCESSION NUMBER)
(THRU)
(NASA-CR-71246) MODEL SPECIFICATION SNAP-8, NUCLEAR POWER CONVERSION SYSTEM MODEL AGAN-0010 (Aerojet-General Corp., Azusa, Calif.) 50 p
N75-75427
Unclas
00/98 23587

SNAP 8

Nuclear Power Conversion System

MODEL AGAN-0010 [U]



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Available to NASA Offices and NASA Centers Only.

CONTRACT NUMBER NAS 5-417

JUL 1975
RECEIVED
NASA STI FACILITY
INPUT BRANCH

POWER/EQUIPMENT DIVISION

Aerojet-General®

CORPORATION

AZUSA, CALIFORNIA • SACRAMENTO, CALIFORNIA

A SUBSIDIARY OF THE GENERAL TIRE AND RUBBER COMPANY

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

C65-10298

PRELIMINARY

AGC-10054A 2 May 1960
Superseding AGC-10054 1 December 1959

MODEL SPECIFICATION

SNAP-8

NUCLEAR POWER CONVERSION SYSTEM MODEL AGAN-0010 [U]

CLASSIFICATION CHANGE
To UNCLASSIFIED
By authority of NASA Ltr TD 2-3-29
Changed by D. Hubbard Date 6/21/67
Classified Document Master Control Station, NASA
Scientific and Technical Information Facility

Contract No. NAS 5-417

Available to NASA Offices and NASA Centers Only.

NOTE: This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, USC, Sections 793 and 794. The transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

AEROJET-GENERAL CORPORATION

Azusa, California

~~CONFIDENTIAL~~

EXCLUDED FROM THE GDS

CONTENTS

Paragraph		Page
1.	SCOPE	1
1.1	Scope	1
1.2	Classification	1
2.	APPLICABLE DOCUMENTS	2
2.1	Government documents	2
2.2	Aerojet-General Corporation documents	3
2.3	Publication	3
3.	REQUIREMENTS	3
3.1	Performance characteristics	3
3.1.1	Compatibility	3
3.1.2	Working fluids	3
3.1.2.1	Primary loop	3
3.1.2.1.1	Temperature	3
3.1.2.1.2	Pressure	3
3.1.2.2	Secondary loop	4
3.1.2.2.1	Temperature and pressure	4
3.1.3	Power level	4
3.1.4	Power outputs	4
3.1.5	Life	4
3.1.6	Servicing prior to launching	4
3.1.7	Startup	4
3.1.7.1	Sequence	4
3.1.8	Shutdown	5
3.1.8.1	Sequence	6
3.1.9	External power	6
3.1.10	Lubricants	6
3.1.11	Leakage	6
3.1.12	Gyroscopic moments	6
3.1.13	Radio interference	6
3.2	Environmental conditions	6
3.2.1	Accelerations	6
3.2.2	Vibration	6
3.2.3	Radiation Dose levels	7
3.2.4	Exposure conditions	7
3.2.4.1	Storage, installation, and handling	7
3.3	Drawings and data	7
3.3.1	Weight of PCS assembly	7
3.3.2	Overall dimensions	9

CONTENTS (cont.)

Paragraph		Page
3.4	Components and subsystems	9
3.4.1	Power-drive assembly	9
3.4.1.1	Turbine	9
3.4.1.2	Alternator	9
3.4.1.2.1	Type	10
3.4.1.2.2	Cooling	10
3.4.1.2.3	Internal operating environment	10
3.4.1.2.4	Bearings	10
3.4.1.2.5	Seals	11
3.4.1.2.6	Weight	11
3.4.1.3	Mercury pump	11
3.4.1.3.1	Centrifugal pump	11
3.4.1.3.2	Jet booster pump	11
3.4.1.3.3	Weight	11
3.4.2	Boiler assembly	11
3.4.3	Radiator assembly	12
3.4.4	Mercury start system	13
3.4.4.1	Mercury reservoir assembly	13
3.4.4.1.1	Operation	13
3.4.4.2	Sequence control unit	13
3.4.4.2.1	Operation	13
3.4.4.3	Battery	14
3.4.4.3.1	Battery requirements	14
3.4.5	Frequency-regulation system	14
3.4.5.1	Frequency-control unit	15
3.4.5.2	Resistance load unit	15
3.4.6	Voltage regulation system	15
3.4.7	Reactor coolant pump	16
3.4.7.1	Centrifugal pump	16
3.4.7.2	Induction motor	16
3.5	Fabrication	17
3.5.1	Materials	17
3.6	Workmanship	17
4.	QUALITY ASSURANCE PROVISIONS	17
4.1	General	17
5.	PREPARATION FOR DELIVERY	17
5.1	Storage, shipment, and delivery	17

ILLUSTRATIONS

	Figure
PCS Schematic Diagram	1
PCS Temperature-Entropy Chart	2
PCS Assembly Drawing	3
Power-Drive Assembly Drawing	4
Typical Turbine/Mollier Diagram	5
Typical Mercury-Pump Characteristics	6
Boiler Assembly Drawing	7
Boiler Temperature-Gradient Characteristics	8
Radiator Assembly Drawing	9
Mercury Reservoir Assembly Drawing	10
Sequence Control Unit, Electrical Diagram	11
Frequency Regulator, Electrical Diagram	12
Voltage Regulator, Electrical Diagram	13
Reactor Coolant Pump, Assembly Drawing	14
Typical Reactor-Coolant-Pump Characteristics	15

	Table
PCS Assembly, Weight Summary	I

1. SCOPE

1.1 Scope.- This specification covers the requirements for the Aerojet-General Model No. AGAN-0010 Power Conversion System, for the National Aeronautics and Space Administration (NASA) SNAP-8 Program.

1.2 Classification.- The Model AGAN-0010 Power Conversion System, hereinafter referred to as the PCS (shown schematically in Figure 1), consists of the following components and subsystems:

(a) A shell-and-tube boiler, which transfers the thermal energy of the nuclear reactor coolant into the secondary loop fluid, mercury.

(b) A primary-loop, reactor-coolant, mechanical pump. The pump circulates the primary-loop fluid from the reactor through the boiler and back to the reactor.

(c) A multistage, pressure-compounded, axial-flow, impulse turbine. It has overhung wheels mounted on a common shaft with the alternator; it is driven by superheated mercury vapor.

(d) A brushless, electromagnetically excited, 6-pole, alternator having dual, three-phase, series-connected stators. It shall supply 30 kva, with a unity power factor.

(e) A lightweight, tube-and-fin, fixed condensing temperature radiator. It shall be of flexible structural design to permit folding and extending without hinged flow passages or rotating seals.

(f) A combination jet-centrifugal mercury pump, mounted on a common shaft with the alternator and used for circulation of the secondary-loop working fluid.

(g) A mercury reservoir assembly, consisting of a pressurizing-gas bottle integral with a mercury storage container, an explosive valve, a burst diaphragm, a flow-control orifice, an explosive-actuated tube closer, and a check valve, to supply the turbine with power for the initial starting period of 180 sec and to fill the secondary loop with the working fluid.

(h) A frequency regulator and loading system, consisting of two tuned circuits to sense frequency change (one circuit shall be tuned at the upper limit and one circuit tuned at the lower limit of the regulated frequency); a single-phase, self-saturating, control magnetic amplifier; three saturable reactors with a stabilizing winding connected to a winding on the magnetic amplifier; and three resistance loads.

(i) An intersecting-impedance, voltage-regulator system. It consists of two circuits: one a non-linear impedance, and the other a linear impedance in which there is one voltage at which the impedance of these two circuits is the same. Other major parts are a three-phase, self-saturating control magnetic amplifier and rectifier, a static exciter, and a differential feedback device to prevent oscillation.

(j) A sequence control system consisting of a hermetically sealed rotary inverter, a high-temperature thermal switch, a timer, a current transformer, and two relays to control the initial starting sequence.

(k) A starting battery, to be used for the initial electrical power required by the reactor coolant pump and startup sequencing operations. The battery shall be a dry-charged, silver-zinc, explosive-squib-activated, primary type.

2. APPLICABLE DOCUMENTS

2.1 Government documents.- The following specifications, of the issue in effect on the date of the request for a proposal, form a part of this specification to the extent specified herein:

MIL-M-191	Mercury
MIL-N-6011	Nitrogen; Liquid and Gas
MIL-I-6181	Interference Limits Test and Design Requirements, Aircraft Electrical Equipment

MIL-E-5272 Environmental Testing, Aeronautical and Associated Equipment, General Specification for.

2.2 Aerojet-General Corporation documents.- The following drawings and publication, of the issue in effect on the date of the request for the proposal, form a part of this specification to the extent specified herein:

P-060090 - Power Conversion System Assembly

2.3 Publication.- Quality Control Policies and Procedures Manual.

3. REQUIREMENTS

The ratings and figures contained herein are estimates based on the terms and conditions defined herein.

3.1 Performance characteristics.- A temperature-entropy chart for the thermodynamic cycle of the system is shown in Figure 2.

3.1.1 Compatibility.- The PCS shall be designed to match the nuclear reactor being developed by the Atomic Energy Commission, (AEC), as specified by the National Aeronautics and Space Administration (NASA) for the program designated SNAP-8, and shall convert the thermal energy produced by this nuclear reactor to electrical power. The operation of two PCS assemblies in parallel with a single reactor shall be considered in the design, with a minimum of modifications. In addition, the PCS, with modifications, shall be so designed that it can be used with a solar-collector, heat-power source, as well as with the nuclear reactor, although the nuclear design should not be compromised to make it an optimum, solar-powered system.

3.1.2 Working fluids.-

3.1.2.1 Primary loop.- The heat-transfer fluid in the primary loop of the PCS (reactor coolant) shall be liquid sodium-potassium alloy (NaK).

3.1.2.1.1 Temperature.- The fluid operating temperature in the primary loop shall not exceed a maximum of 1350°F.

3.1.2.1.2 Pressure.- The fluid operating pressure in the primary loop shall not exceed a maximum of 40 psia.

3.1.2.2 Secondary loop.- The working fluid in the secondary loop of the PCS shall be liquid mercury, per specification MIL-M-191.

3.1.2.2.1 Temperature and pressure.- The fluid operating temperatures and pressures of the PCS shall be as shown in Figure 1.

3.1.3 Power level.- The PCS shall develop a nominal electrical power of 30 kw. It shall be capable of operation over a range from zero to full power.

3.1.4 Power outputs.- The PCS shall be capable of electrical power output for use in a propulsion system, communication, guidance, and controls during space missions, and be convertible to supply power for communication when the vehicle reaches its planetary objective. The output power, voltage regulation, harmonic content, and frequency regulation are as follows:

Output Load Range, kw	0 to 30
Frequency Control, cps	1000±1%
Voltage, ac	43.6/75.6
Voltage Regulation	±5% (from 3 to 30 kw)
Harmonic Content (rms)	<5%
Harmonic Content (individual)	<3%

3.1.5 Life.- The PCS shall be designed to attain an ultimate duration of unattended, full-power operation of 10,000 hours. Ground tests shall be required for these life durations at conditions that simulate as closely as possible the environmental conditions that will be encountered in launching, startup, operation, and shutdown.

3.1.6 Servicing prior to launching.- The pressurizing gas bottle of the mercury reservoir shall be pressurized with nitrogen to 550 psig.

3.1.7 Startup.- The PCS shall be capable of starting while in orbit, upon ground command, within ambient temperature limits to be specified when detailed information becomes available. Restarting shall not be required.

3.1.7.1 Sequence.- The events shall take place as follows:

(a) Reactor starts; the power for control motors shall be supplied from a source external to the PCS.

(b) Reactor coolant pump operates at reduced speed and power, using the PCS start battery power. The expansion of the reactor coolant is taken up by the expansion reservoir, which provides pressurization of the reactor coolant.

(c) When the reactor coolant temperature reaches 1100°F at the boiler, the following take place:

(1) Thermal switch energizes explosive valve in mercury storage system.

(2) Nitrogen, originally at 550 psig, flows into a compartment containing mercury in an expulsion bladder.

(3) When mercury pressure reaches 100 psig, it bursts a diaphragm in the outlet piping.

(4) Mercury flows through an orifice which limits the flow rate.

(d) Turbine accelerates, and the speed-control unit acts to hold speed to rated value by applying a resistance load.

(e) When power output exceeds 10 kw, a sensing device switches the reactor coolant pump from battery power, part speed operation, to alternator power, full-speed operation.

(f) When the mercury reservoir is discharged, the system is running stably. After 180 sec have elapsed from the actuation of the explosive valve, a timer shall fire a squib which shall close the mercury supply line from the reservoir to the secondary loop.

(g) Timer will also connect alternator output to vehicle load. The frequency regulator unit automatically applies the correct amount of additional resistive load to absorb the full output of the alternator and keep it at rated speed.

3.1.8 Shutdown.- The PCS shall be capable of shutdown while in orbit upon ground command.

3.1.8.1 Sequence.- Sequence shall be as follows:

(a) Reactor temperature control is over-ridden to shutdown reactor.

(b) Conversion system cools off and alternator slows to a stop.

3.1.9 External power.- The external power required from ground, and missile power supplies shall be specified when information is available.

3.1.10 Lubricants.- Lubrication for the PCS bearings shall be provided by pressurized secondary-loop fluid (mercury per specification MIL-M-191) in liquid state.

3.1.11 Leakage.- The PCS shall be hermetically sealed. There shall be no external leakage of the primary- or secondary-loop working fluids.

3.1.12 Gyroscopic moments.- The net gyroscopic moment of the PCS shall be reduced to a practical minimum. A positive means of balancing the gyroscopic moment shall be provided.

3.1.13 Radio interference.- The limits of the radio interference produced by the PCS shall not exceed those specified in specification MIL-I-6181.

3.2 Environmental conditions.- The PCS shall not suffer any detrimental effects during and after exposure to extreme temperature (test procedure I); to rain, sand, and dust (test procedure I); or to salt spray or fungus, as defined in specification MIL-E-5272.

3.2.1 Accelerations.- The PCS shall be capable, while in a non-operating state, of withstanding a maximum axial acceleration of 7 g, a maximum lateral acceleration of 0.3 g, and a maximum of 4 g of ground-handling load applied in any direction. The acceleration requirements during operating state while in orbit shall be specified when information regarding accelerations imposed upon the PCS by the vehicle is available.

3.2.2 Vibration.- The PCS shall withstand all vibrations encountered in normal usage without impairment of its serviceability. The vibration requirements during non-operating and operating states shall be specified, when detailed information becomes available.

3.2.3 Radiation Dose Levels.- The PCS shall be capable of withstanding a fast-neutron dose of 10^{15} neutrons/cm^2. All radiation dose levels shall be below allowable tolerances on all critical components.

3.2.4 Exposure conditions.-

3.2.4.1 Storage, installation, and handling.- The PCS shall not suffer any detrimental effects when exposed over the ambient temperature range of 0 to 140°F for periods up to 2 years.

3.3 Drawings and data.- The following Aerojet-General drawings form a part of this specification:

(a)	Figure 1	PCS Schematic Diagram, P-065886
(b)	Figure 3	PCS Assembly, Drawing P-065885
(c)	Figure 4	Power-Drive Assembly, Drawing P-065884
(d)	Figure 7	Boiler Assembly, Drawing P-065887
(e)	Figure 9	Radiator Assembly, Drawing P-060096
(f)	Figure 10	Mercury Reservoir Assembly, Drawing P-060097
(g)	Figure 11	Sequence Control Unit, Electrical Diagram, Drawing P-060099
(h)	Figure 12	Frequency Regulator, Electrical Diagram, Drawing P-068453
(i)	Figure 13	Voltage Regulator, Electrical Diagram, Drawing P-068452
(j)	Figure 14	Reactor Coolant Pump Assembly, Drawing P-065888

3.3.1 Weight of PCS assembly.- The estimated weight of the PCS assembly is 695 lb. A detailed weight breakdown of the PCS assembly is shown in Table I.

TABLE I

PCS ASSEMBLY, WEIGHT SUMMARY

	Weight, lb	
THERMAL COMPONENT GROUP	474	
Radiator Assembly		240
Boiler Assembly		102
Turbine Assembly		14
Mercury Liquid		42
Reactor Coolant (not including reactor inventory)		76
ELECTRICAL GROUP	113	
Alternator Assembly		45
Resistance Load Assembly		5
Frequency Regulator and Loading Assembly		34
Sequence Control Assembly		8
Voltage Regulator Assembly		6
Harness Assembly		5
Battery (Starting)		10
PUMP AND FLOW CONTROL GROUP	45	
Reactor Coolant Pump Assembly		16
Reactor Coolant Reservoir Assembly		12
Mercury Pump Assembly		2
Mercury Reservoir Assembly		15
PIPING AND HARDWARE GROUP	22	
Reactor Coolant Piping		7
Mercury Piping		5
Brackets, Nuts, Bolts		10

	Weight, lb
INSULATION	8
MISCELLANEOUS (5%)	33
TOTAL PCS WEIGHT	695

3.3.2 Overall dimensions.- The estimated overall dimensions of the PCS assembly less the radiator (3.4.3) are shown in Aerojet Drawing P-065885 Figure 3.

3.4 Components and subsystems.- The following descriptions are based on preliminary design estimates.

3.4.1 Power-drive assembly.- The PCS power-drive assembly shall consist of a turbine, alternator, and mercury pump mounted on a common shaft. The design, configuration and overall dimensions are shown in Figure 4. This assembly shall be hermetically sealed.

3.4.1.1 Turbine.- The turbine design estimates for working fluid of mercury vapor are

(a)	Power, hp	50.5
(b)	Speed, rpm	20,000
(c)	Inlet temperature, ^{o}F	1200
(d)	Inlet pressure, psia	275
(e)	Exhaust pressure, psia	20
(f)	Wheel OD, in.	4.73
(g)	Efficiency, %	67

The turbine shall be a multistage, pressure-compounded, axial-flow, impulse machine which operates at a constant speed. The turbine shall be attached directly to the alternator shaft and shall be supported by the alternator journal bearings. The predicted thermodynamic processes are shown by the Mollier diagram, Figure 5. The estimated weight of the turbine assembly is 14 lb.

3.4.1.2 Alternator.- The alternator design estimates are

(a)	Output rating, kva	33
(b)	Power factor	1
(c)	Voltage (ac)	43.6/75.6, 3-phase, 4-wire
(d)	Frequency, cps	1000
(e)	Speed, rpm	20,000
(f)	Coolant	liquid mercury
(g)	Coolant Temperature, ^{o}F	560
(h)	Internal environment	mercury vapor
(i)	Efficiency, percent	90

3.4.1.2.1 Type.- Alternator shall be a brushless disc-type driven by a turbine which is mounted in an overhung manner on a common shaft. It shall have two rotors, two stators, and one stationary field coil. The excitation shall be provided by a voltage regulator. The stator windings shall be electrically connected in series.

3.4.1.2.2 Cooling.- The disc alternator shall be cooled by circulating liquid mercury around the outside case.

3.4.1.2.3 Internal operating environment.- The internal operating environment of the alternator components shall be mercury vapor at a pressure of 20 psia and a temperature no less than $706^{o}F$. The stator and field coil shall be hermetically sealed inside this environment.

3.4.1.2.4 Bearings.- The alternator shall have two journal bearings; one adjacent to and supporting the turbine, and the other adjacent to and supporting the mercury pump. There shall be a smooth-face, thrust-ring bearing which revolves between two, adjustable, thrust-bearing faces. The wear pads on the bearing faces are segments of an annulus spaced equally around the circumference of the bearing faces. These thrust-bearing faces center the rotor and maintain the axial air gap, as well as carry the thrust loads. The bearings shall be pressure-lubricated with liquid mercury from the secondary loop, and shall have no metal-to-metal contact under operating conditions.

3.4.1.2.5 Seals.- The bearings shall have dynamic-type seals, with pumping slinger, and no contact between running and stationary surfaces.

3.4.1.2.6 Weight.- The estimated weight of the alternator assembly is 45 lb.

3.4.1.3 Mercury pump.- The mercury pump shall be a jet-centrifugal pump combination. Its estimated head and efficiency characteristics are shown in Figure 6. The design estimates are

(a)	Head rise, ft	54.5
(b)	Pressure rise, psi	304
(c)	Weight flow, lb/sec	1.81
(d)	Capacity, gpm	1.01
(e)	Suction pressure, psia	15
(f)	Suction temperature, ^{o}F	558
(g)	Speed, rpm	20,000
(h)	Efficiency, percent	30

3.4.1.3.1 Centrifugal pump.- The centrifugal pump impeller shall be of the radial vane type. This impeller shall be made integral with the alternator shaft end nut and overhung from the alternator journal bearings. The pump housing incorporates a simple collector annulus with two discharge diffusers 180^{o} apart in the collector housing. One diffuser shall be used exclusively to deliver the jet-pump flow and the other diffuser delivers the secondary-loop flow.

3.4.1.3.2 Jet booster pump.- The jet booster pump shall be of conventional design utilizing a suction volute, a drive-head discharge nozzle, a mixing tube, and a conical diffuser to match the jet-pump mixing-tube diameter to the eye diameter of the main-stage pump.

3.4.1.3.3 Weight.- The estimated weight of the mercury pump is 2.0 lb.

3.4.2 Boiler assembly.- The PCS boiler assembly design, configuration and overall dimensions are shown in Figure 7. The power-drive assembly shall be attached to the boiler by means of a four-bolt flange, with the mercury vapor outlet welded to the turbine inlet. The boiler design estimates are

		Mercury	Reactor Coolant
(a)	Flow rate, lb/hr	5904	20,000
(b)	Inlet temperature, ^{o}F	667	1300
(c)	Inlet Pressure, psia	310	31
(d)	Outlet Temperature, ^{o}F	1200	1100
(e)	Outlet Pressure, psia	275	20

The boiler shall be a tube-and-shell design. The tubes contain the mercury and the shell contains the reactor coolant. There shall be six mercury tubes which have a twisted ribbon inside to facilitate heat transfer by acting as a centrifugal separator and creating a "g" field within the tube, forcing liquid against the hot tube wall. The six mercury tubes are connected for parallel flow. The temperature gradient characteristics of the boiler are shown in Figure 8. The estimated weight of the boiler assembly without working fluids is 102 lb.

3.4.3 Radiator assembly.- The PCS radiator assembly design, configuration, and overall dimensions are shown in Figure 9. The radiator requires the vehicle's skin and the structure between the radiator and sking to be jettisoned. The radiator shall be a lightweight design of tube-and-fin, extended-surface construction with a fixed condensing temperature. The radiator design estimates are

(a)	Tube material	stainless steel
(b)	Tube outside diameter, vapor side, in.	0.5
(c)	Tube wall thickness, vapor side in.	0.05
(d)	Tube spacing, in.	3.5
(e)	Fin material	aluminum
(f)	Fin thickness, in.	0.01
(g)	Thermal gradient, ^{o}F	216
(h)	Total effective area, ft^2	800
(i)	Watts per ft^2	325
(j)	Weight per ft^2, lb	0.3

The radiator shall have condensing tubes and extended fins between a mercury-vapor manifold and a liquid-mercury manifold. The tubes shall have a twisted ribbon

inside which acts as a centrifugal separator causing mercury liquid droplets to collect at the walls. The tubes shall have orifices so placed to allow liquid to flow into additional tube length for sub-cooling. The radiator assembly shall be a flexible structure permitting folding and extending without hinged flow passages or rotating seals. The manifolds and tubes shall have meteorite protection for operation in the extended position, in accordance with the requirements of Whipple's data, "Meteoritic Risk to Space Vehicles." The estimated weight of the radiator is 240 lb.

3.4.4 Mercury start system.-

3.4.4.1 Mercury reservoir assembly.- The mercury reservoir assembly shall consist of a bottle of nitrogen at high pressure, with a separate compartment holding mercury inside an expulsion bladder; an explosive valve; a burst diaphragm; a flow-control orifice; an explosive-actuated tube closer; and a check valve. The mercury reservoir assembly is shown in Figure 10, and its estimated dry weight is 15 lb.

3.4.4.1.1 Operation.- The explosive valve is actuated by a signal from the temperature sensing switch (3.4.4.2). This allows the nitrogen to flow from its storage compartment into the space between the expulsion bladder and its compartment. When the pressure on the mercury reaches a preset value, the diaphragm at the outlet of the bladder is ruptured, and the mercury flows into the secondary loop through an orifice to control the flow rate. An explosive-actuated tube closer isolates the empty mercury reservoir from the loop, and a check valve prevents any reverse flow to the mercury reservoir before the tube closer is actuated.

3.4.4.2 Sequence control unit.- The sequence control unit shall consist of a hermetically sealed rotary inverter (converting dc to ac); a high-temperature sensing switch; a timer, a current transformer; and relays to control the starting sequence. The electrical circuit is shown in Figure 11, and its estimated weight is 8 lb.

3.4.4.2.1 Operation.- The high-temperature sensing switch when activated, connects the battery to the inverter. The inverter operates the reactor coolant

pump at partial speed. An alternator output-sensing device switches the reactor coolant pump from inverter to alternator power. As the machine approaches design speed, the frequency-control device (3.4.5) applies a resistance load to control the speed. Current flowing in the main circuit energizes a current transformer which is connected in series with a fusible link, one-time-operation relay. At a predetermined value of current, the link will melt and allow the three contacts of the main circuit to close and thereby connect the alternator to the vehicle load. The frequency-control device applies the correct amount of aupplemental resistance load to keep the alternator at rated speed.

3.4.4.3 Battery.- The battery shall furnish power to drive the inverter which in turn drives the reactor coolant pump. It also shall furnish power to actuate the explosive squibs and any other device needing electrical power during the first phases of start-up.

3.4.4.3.1 Battery requirements.- Battery shall be a silver-zinc, primary-type battery, suitable for one discharge only. The case shall be leak-proof to permit operation in any attitude. The battery shall be supplied dry-charged. Activation shall be accomplished by the firing of a squib, which will allow gas pressure from a storage container to force the electrolyte from its shipping compartment into all the cells of the battery. The battery operates at either a high or low discharge rate. The battery design estimates are

(a)	Discharge rate, maximum amps	60
(b)	Voltage regulation, percent	±5
(c)	Capacity, ampere-hours	4
(d)	Activation time, maximum sec.	3
(e)	Service period, maximum min.	12
(f)	Voltage, average, dc	28

The estimated weight of the battery is 10 lb.

3.4.5 Frequency-regulation system.- The frequency-regulation system shall consist of a frequency-control unit and a resistance load unit. Frequency

regulation is maintained within ±1 percent of the selected frequency. The electrical circuit is shown in Figure 12.

3.4.5.1 Frequency-control unit.- The frequency-control unit shall be provided with liquid mercury coolant from the secondary loop, and employs two tuned circuits to sense frequency change. One circuit tuned above the regulated frequency, and one circuit tuned below the regulated frequency. These circuits supply output to the single-phase, self-saturating, magnetic amplifier which supplies output to the control windings of three saturable reactors. The saturable reactors allow current flow to the resistive load. A winding on the saturable reactors shall be connected to a winding on the magnetic amplifier to prevent system oscillation. The estimated weight of the frequency control is 34 lb.

3.4.5.2 Resistance load unit.- The resistance load unit shall consist of high-temperature resistance wire wound spirally over a layer of insulation placed around a section of reactor coolant pipe between the pump and the reactor. Another layer of insulation shall be placed over the wire and a metal tube placed on the outside. The estimated weight of the resistance load unit is 5 lb.

3.4.6 Voltage regulation system.- The voltage regulator shall operate on the intersecting impedance principle. Two circuits sense the output voltage of the alternator. One circuit is a non-linear impedance, which (say) tends to lower the excitation; the other is a linear impedance, which (say) tends to raise the excitation. There shall be one voltage where the impedance of these two circuits is equal. At this point of intersection of the two impedance curves, there is equal output to the three-phase, magnetic amplifier control windings. If the voltage rises, the current in the winding tending to lower the excitation increases more than the current in the winding tending to raise the excitation. The result is that the generator excitation is lowered. If the voltage drops below the intersection point, the current in the winding tending to raise the excitation drops less than the current in the winding tending to lower the excitation. The result is that the generator excitation is raised. In this manner, the voltage of the generator is held within required tolerance as the load on the

generator changes. A differential feedback device will be used to prevent oscillation if the closed-loop system consisting of the magnetic amplifier, saturable reactors, and alternator field winding shows instability. The electrical circuit is shown in Figure 13. The estimated weight of the voltage regulation system is 6 lb.

3.4.7 Reactor coolant pump.- The reactor coolant pump design, configuration, and overall dimensions are shown in Figure 14. It shall be a canned-rotor, mechanical, centrifugal pump mounted directly on the shaft of an a-c induction motor, which operates from power supplied from ground, vehicle, or PCS outputs. The suction pressure shall be provided by the reactor coolant expansion reservoir. The estimated weight of the reactor coolant pump is 16 lb.

3.4.7.1 Centrifugal pump.- The centrifugal pump design estimates are

(a)	Speed, rpm	6330
(b)	Capacity, gpm	55
(c)	Head rise, ft	47.5
(d)	Suction temperature, ^{o}F	1100
(e)	Suction pressure, psia	20
(f)	Specific speed	2580
(g)	Efficiency, percent	62

The typical pump characteristics are shown in Figure 15. The pump utilizes a conventional open impeller of the mixed-flow type and a free-vortex volute discharge housing and conical diffuser. The axial-thrust load due to the impeller is alleviated by radial vanes machined on the back of the impeller.

3.4.7.2 Induction motor.- The induction motor shall be an 18-pole, three-phase, radial-air-gap machine, with a hermetically sealed stator assembly. The rated motor output is 1.0 hp at 6330 rpm, and 5 percent slip. The motor shall be cooled by liquid mercury, from the secondary loop, circulating in a jacket around the outside of the stator. The drive shaft is relatively long with minimum cross sectional area to reduce heat flow from the reactor coolant to the motor. The

shaft has two journal-type bearings for the motor, which are lubricated with the reactor coolant.

3.5 Fabrication.-

3.5.1 Materials.- Materials used in manufacture of all components shall be of the highest quality suitable for the purpose intended, subject to contractual specification.

3.6 Workmanship.- The workmanship and finish shall be of sufficiently high grade to insure satisfactory operation, reliability, and durability consistent with the service life of the PCS and the requirements of this specification.

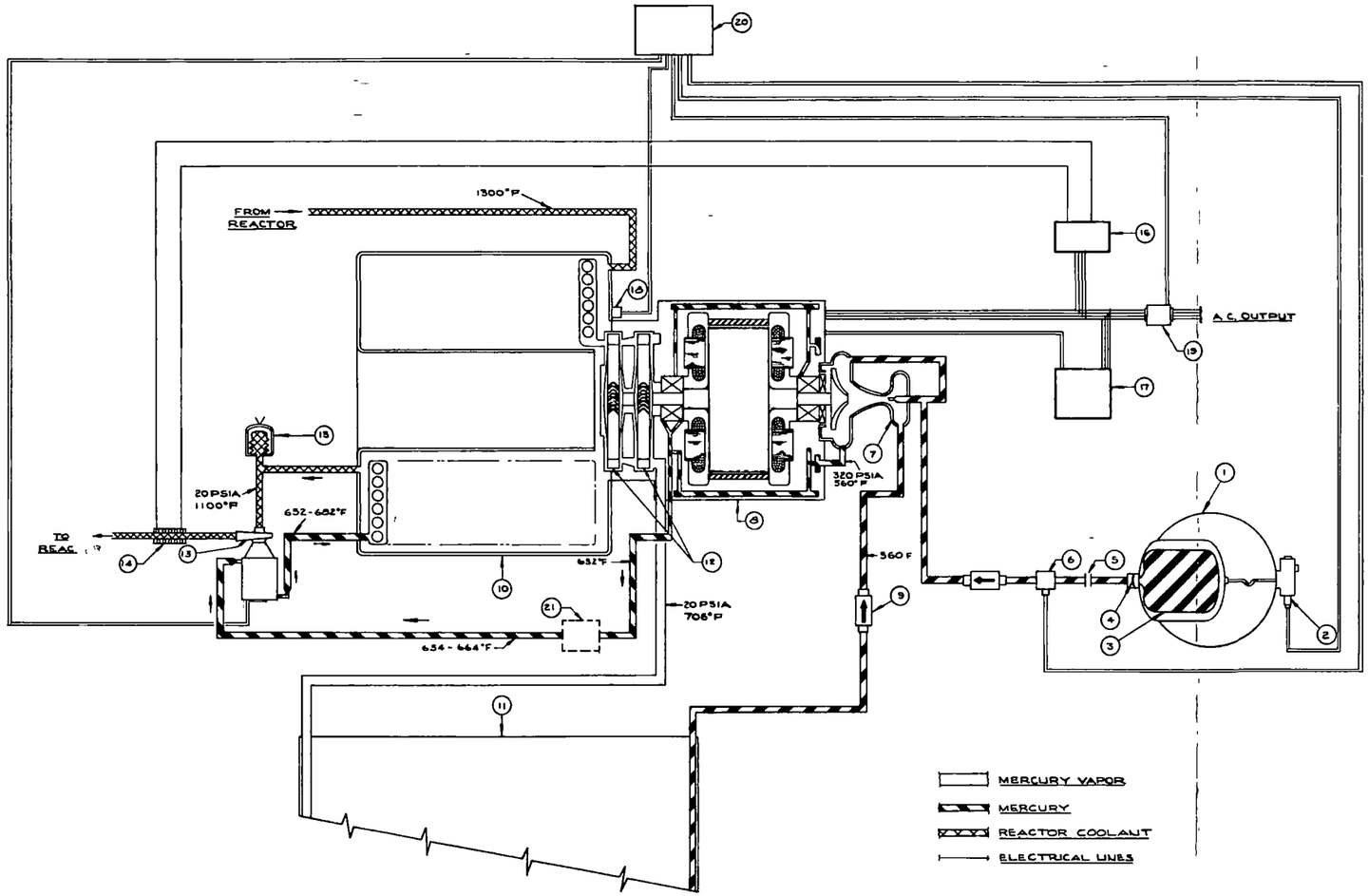
4. QUALITY ASSURANCE PROVISIONS

4.1 General.- The provisions of quality assurance are set forth in the Quality Control Policies and Procedures Manual.

NOTE: The Aerojet-General Corporation Quality Control Division has established this manual to assure that the products of the company meet acceptable standards of quality.

5. PREPARATION FOR DELIVERY

5.1 Storage, shipment, and delivery.- The requirements for preservation and packaging shall cover cleaning, drying, and preservative methods adequate to prevent deterioration; appropriate protective wrappings, package cushioning, and interior containers; and package identification. The requirements shall be incorporated into a control specification.

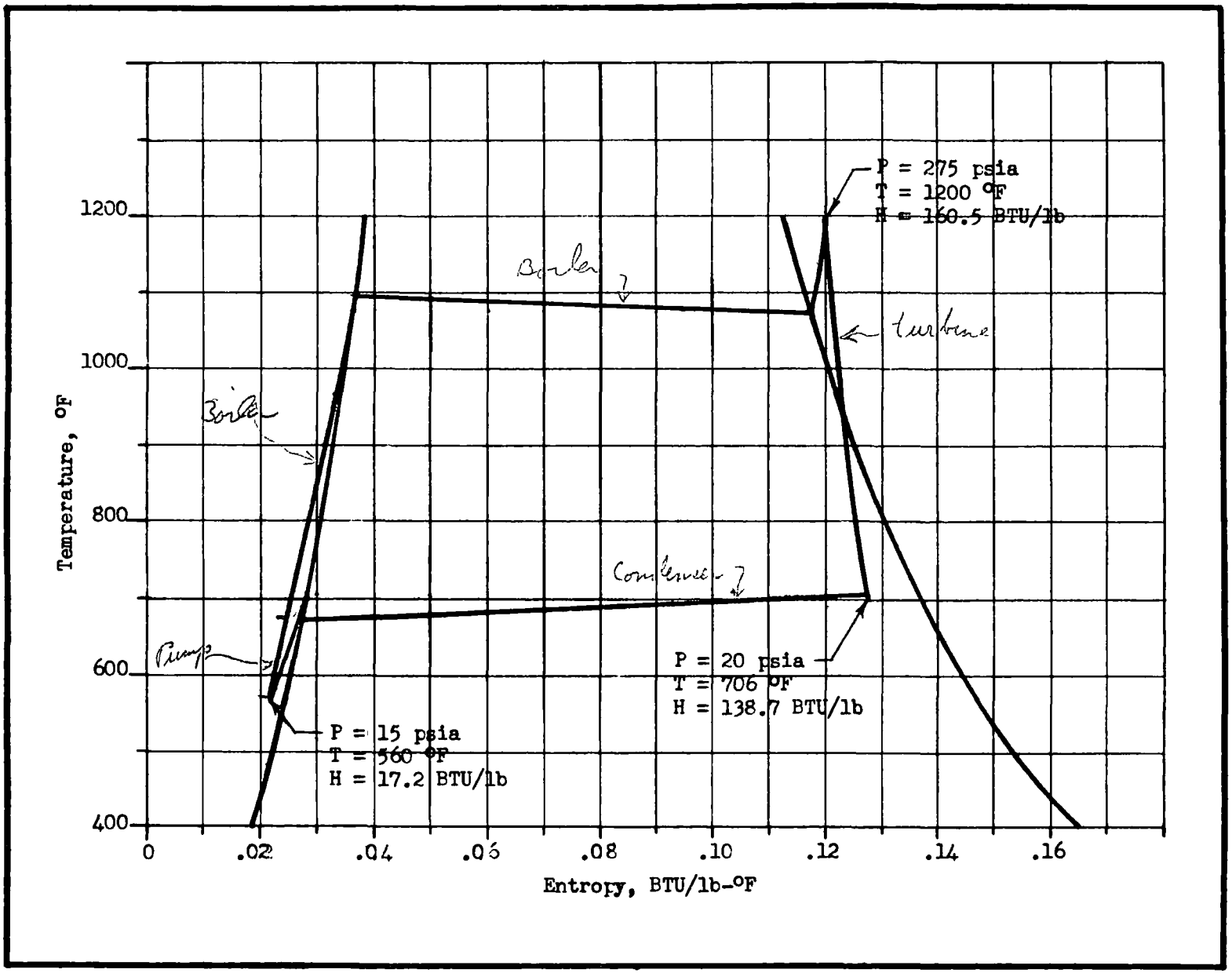


1. NITROGEN TANK
2. EXPLOSIVE VALVE
3. MERCURY EXPULSION BLADDER
4. DIAPHRAGM
5. ORIFICE
6. EXPLOSIVE TUBE CLOSER
7. MERCURY PUMP
8. ALTERNATOR
9. CHECK VALVE
10. MERCURY BOILER
11. RADIATOR
12. TURBINE
13. REACTOR COOLANT PUMP
14. PARASITIC LOAD RESISTOR
15. REACTOR COOLANT EXPANSION RESERVOIR
16. FREQUENCY REGULATOR
17. VOLTAGE REGULATOR
18. 1100°F SENSING SWITCH
19. POWER TRANSFER RELAY
20. SEQUENCE CONTROL UNIT
21. HIGH TEMP FREQ & VOLT REG. COMPONENTS

	4-28-60	PCS SCHEMATIC DIAGRAM	AEROJET GENERAL CORPORATION AZUSA, CALIFORNIA
			P-065886
	4-28-60		

~~CONFIDENTIAL~~ Figure 1

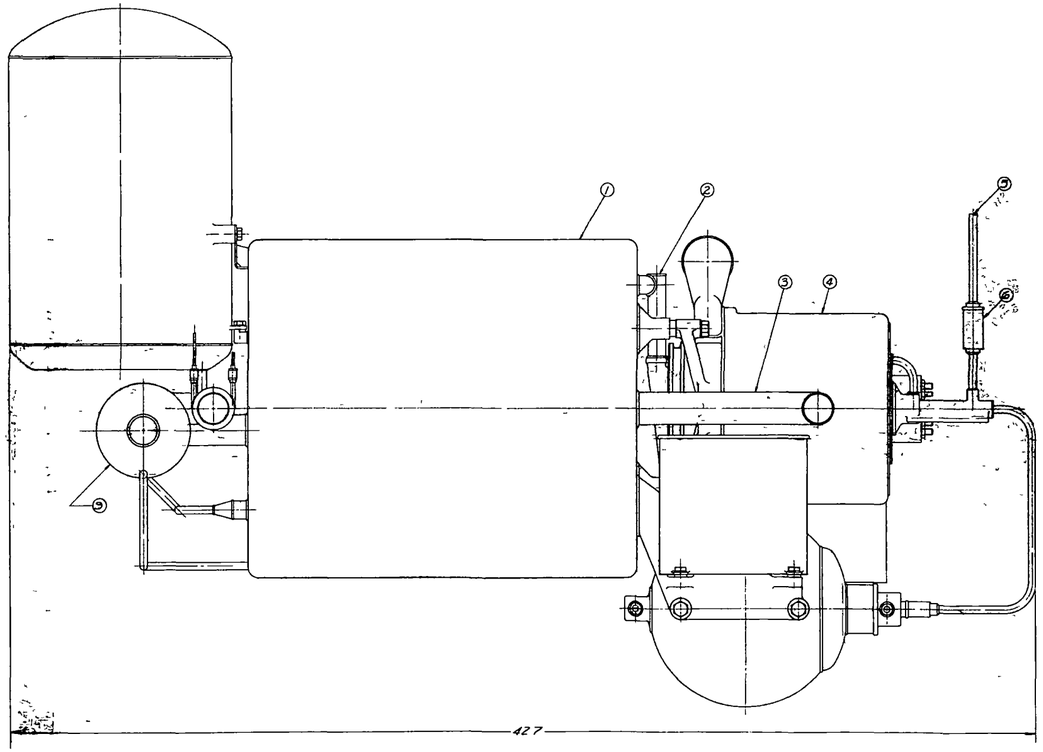
CONFIDENTIAL

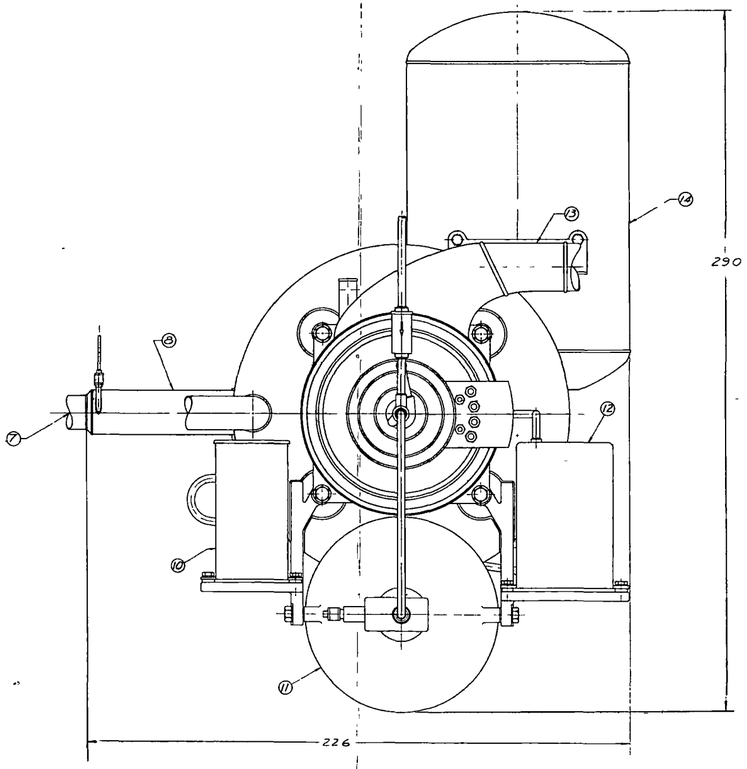


PCS Temperature-Entropy Chart

Figure 2

CONFIDENTIAL





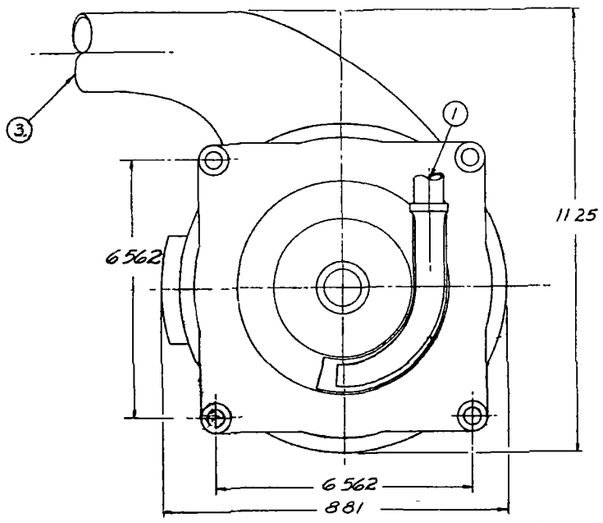
1. BOILER ASSEMBLY
2. TURBINE INLET MANIFOLD
3. COOLANT LINE FROM REACTOR
4. POWER DRIVE ASSEMBLY
5. Hg LINE FROM RADIATOR
6. CHECK VALVE
7. COOLANT LINE TO REACTOR
8. PARASITIC LOAD RESISTOR
9. REACTOR COOLANT PUMP ASSEMBLY
10. SEQUENCE CONTROL UNIT
11. Hg RESERVOIR ASSEMBLY
12. HIGH TEMP CONTROL PACKAGE
13. Hg VAPOR LINE TO RADIATOR
14. REACTOR COOLANT EXPANSION RESERVOIR ASSEMBLY

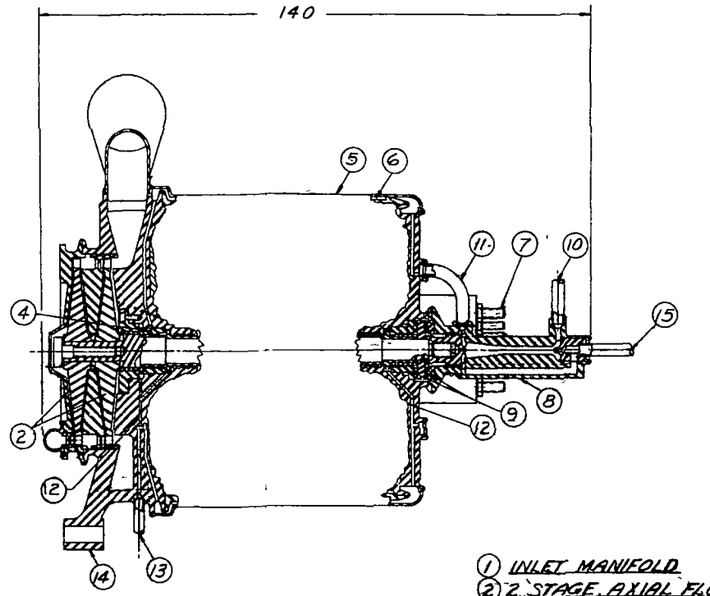
NOTE: FOR CLARITY, NO INSULATION IS SHOWN ON THE REACTOR COOLANT LOOP COMPONENTS, BOILER OR TURBINE.

P.C.S. ASSEMBLY

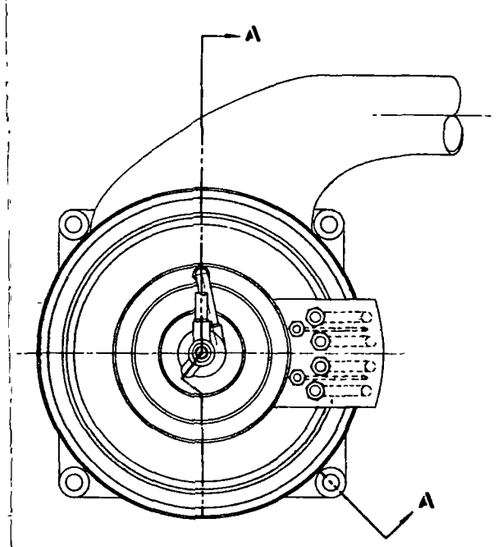
FD63085

Figure 3





SECTION A-A



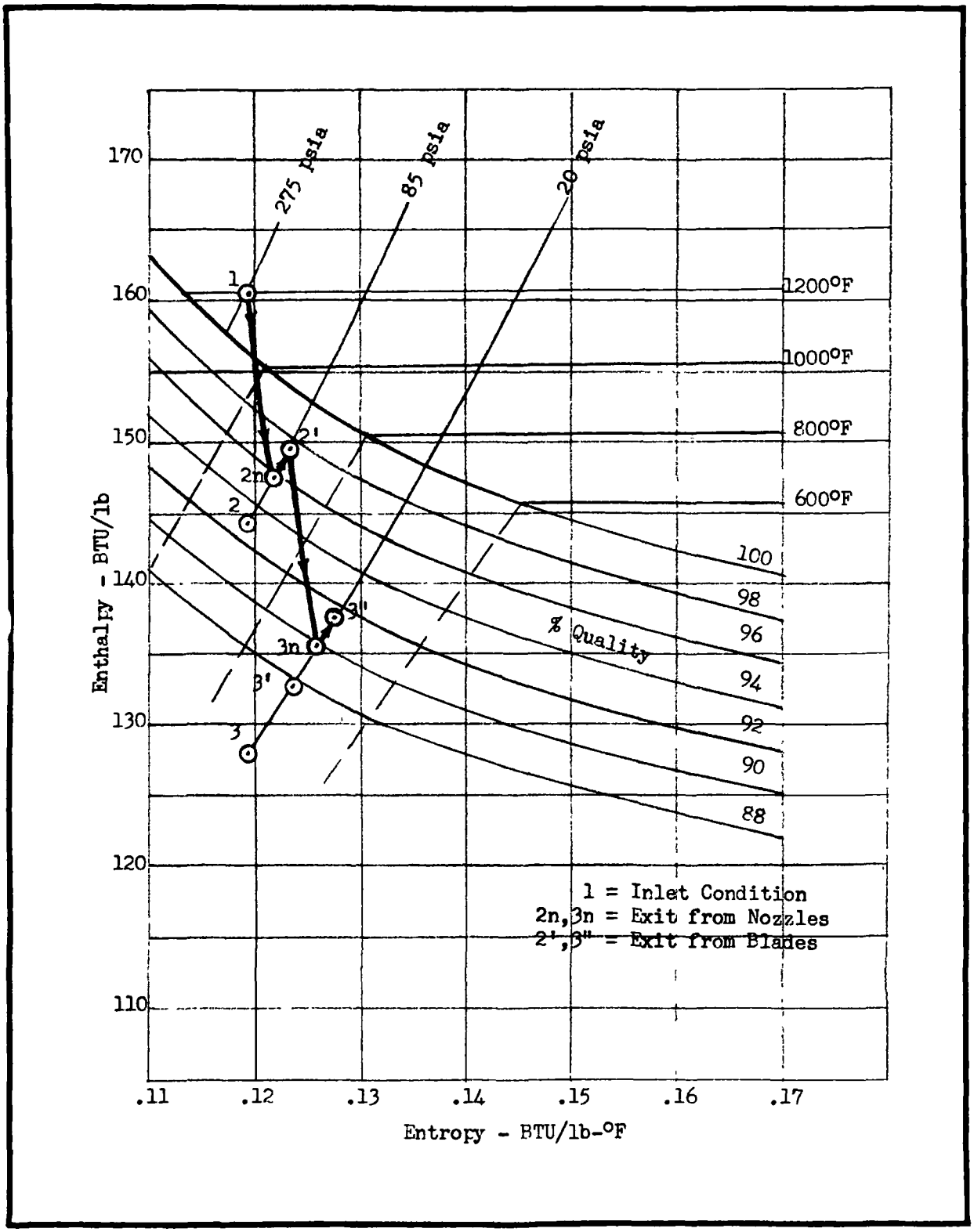
1. INLET MANIFOLD
2. 2 STAGE, AXIAL FLOW, IMPULSE TYPE, TURBINE ASSY
3. EXHAUST MANIFOLD
4. JOURNAL BEARING - MERCURY LUBRICATED
5. BRUSHLESS, AXIAL AIR GAP, ALTERNATOR
6. ALTERNATOR COOLING JACKET
7. ELECTRICAL CONNECTIONS
8. MERCURY PUMP
9. JOURNAL & THRUST BEARING
10. MERCURY INLET
11. MERCURY PUMP DISCHARGE
12. LUBRICANT RETURN LINE
13. MERCURY OUTLET
14. MOUNTING BOSS
15. FROM MERCURY RESERVOIR

POWER DRIVE ASSEMBLY

2063001

~~CONFIDENTIAL~~

Figure 4



Typical Turbine Mollier Diagram

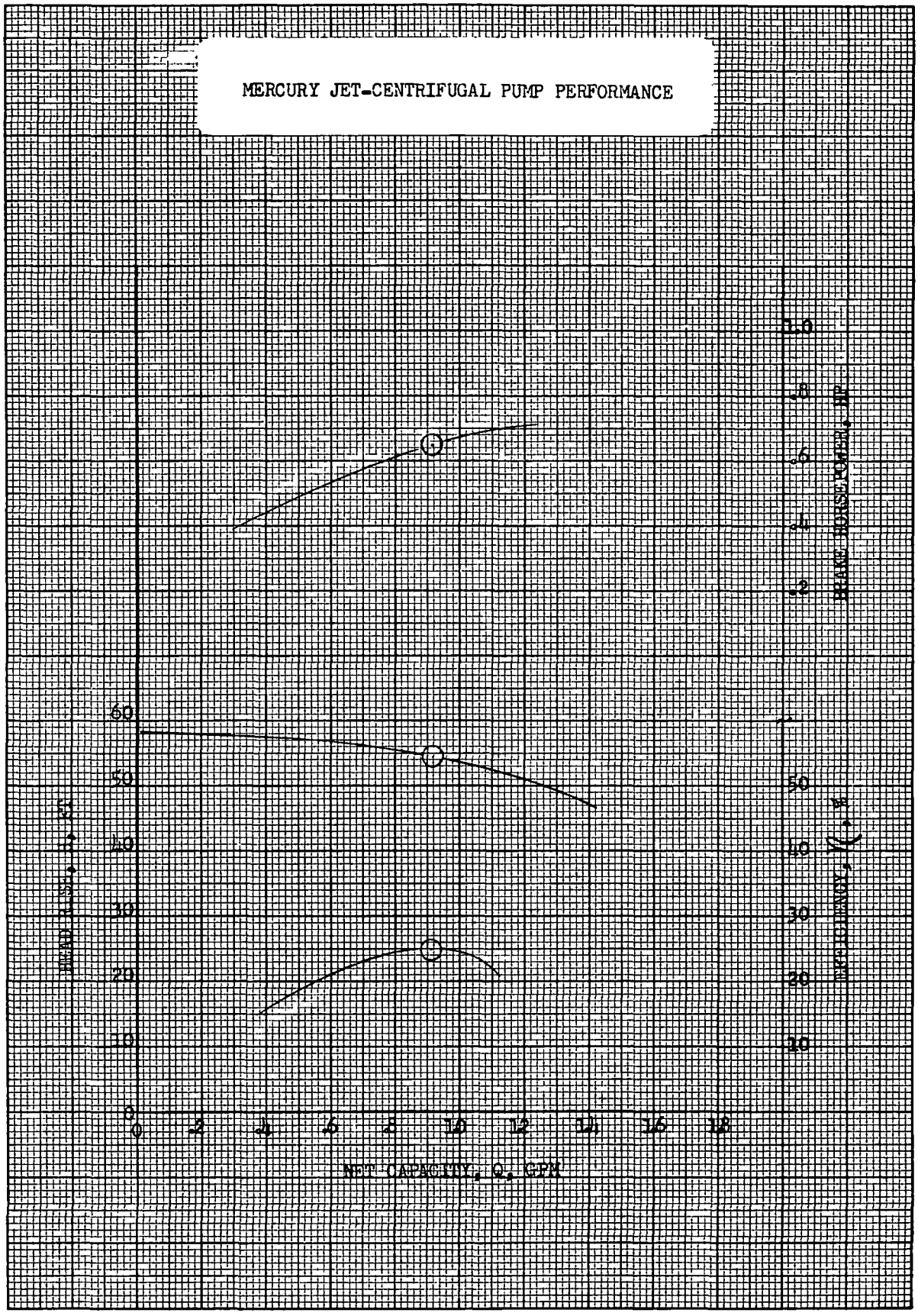
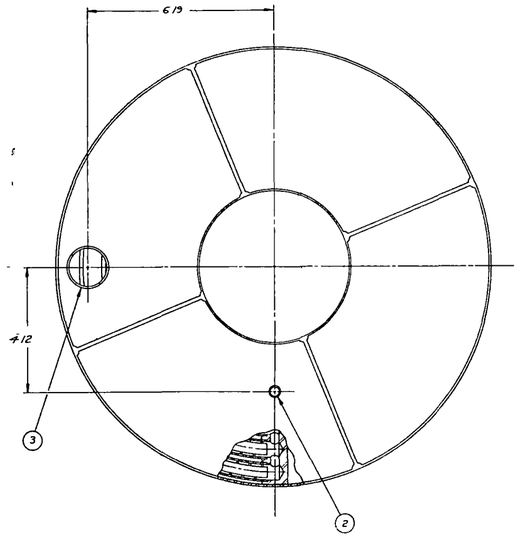
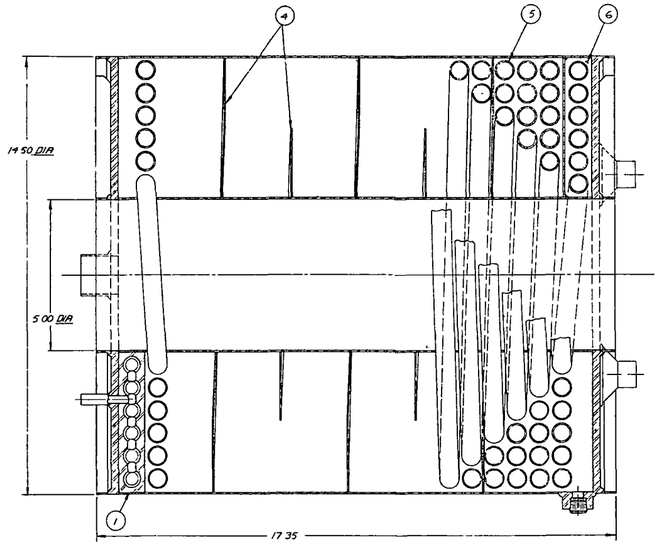
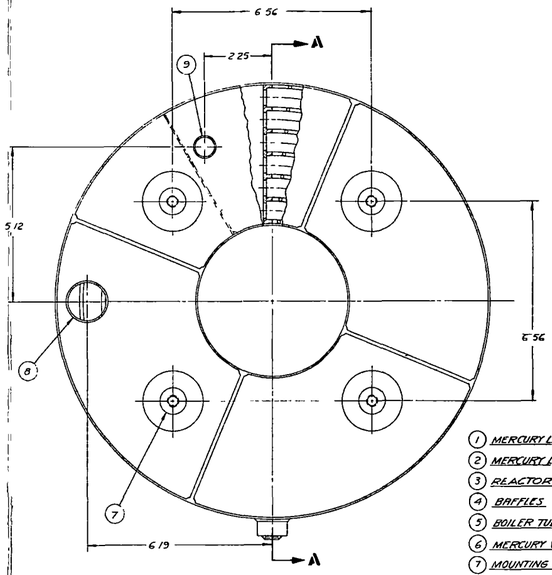

MERCURY JET-CENTRIFUGAL PUMP PERFORMANCE
HEAD, H, FT.
BRAKE HORSEPOWER, BHP
EFFICIENCY, η, %
NET CAPACITY, Q, GPM
0
10
20
30
40
50
60
2
4
6
8
10
12
14
16
18
.2
.4
.6
.8
1.0

Figure 6

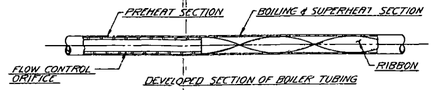




SECTION A-A



1. MERCURY LIQUID MANIFOLD
2. MERCURY LIQUID INLET
3. REACTOR COOLANT OUTLET
4. BAFFLES
5. BOILER TUBING
6. MERCURY VAPOR MANIFOLD
7. MOUNTING BOSS
8. REACTOR COOLANT INLET
9. MERCURY VAPOR OUTLET



DEVELOPED SECTION OF BOILER TUBING

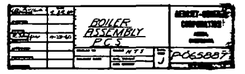
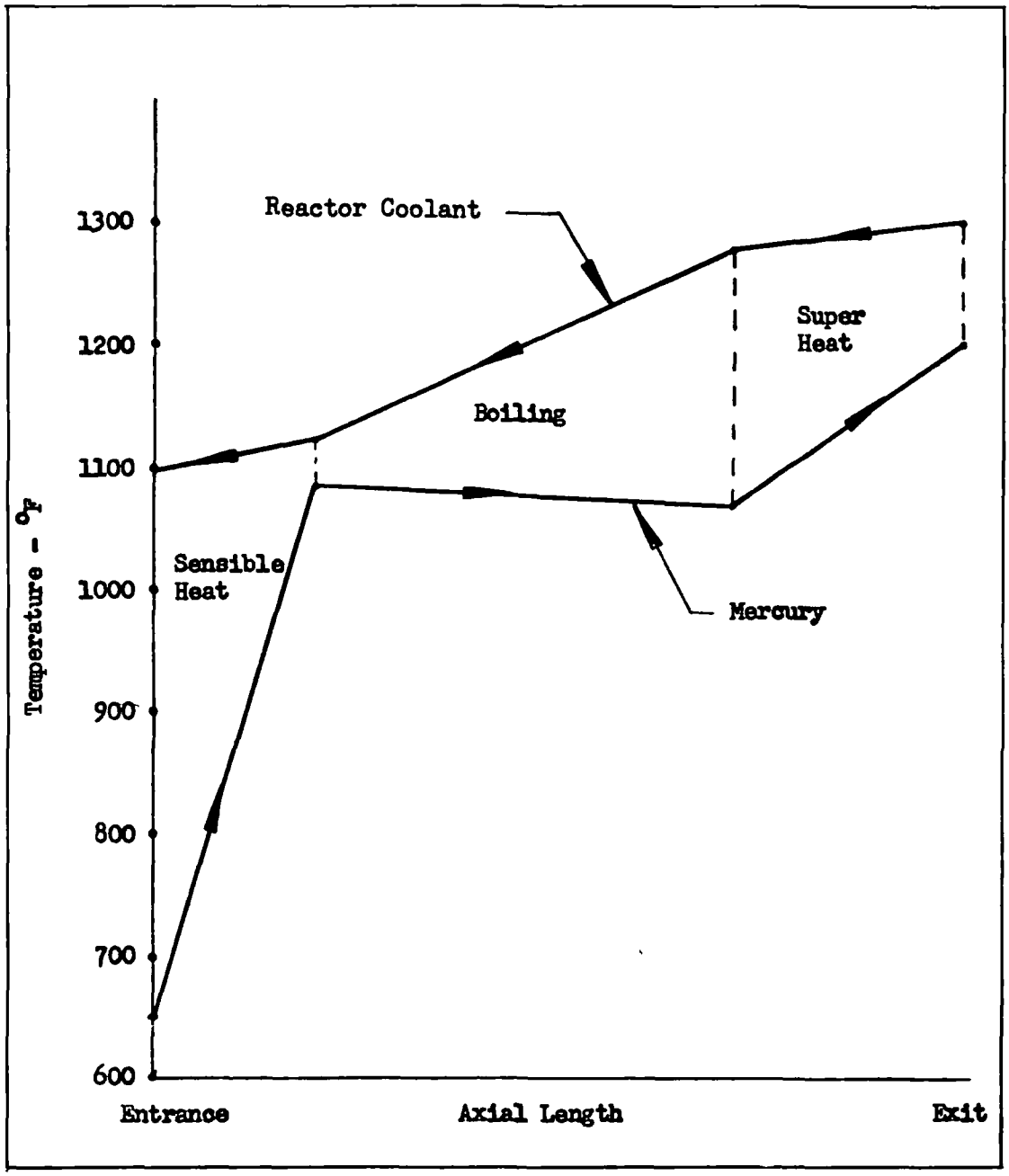
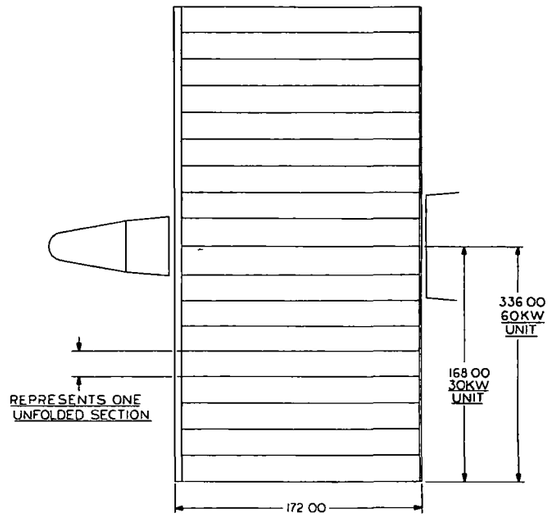


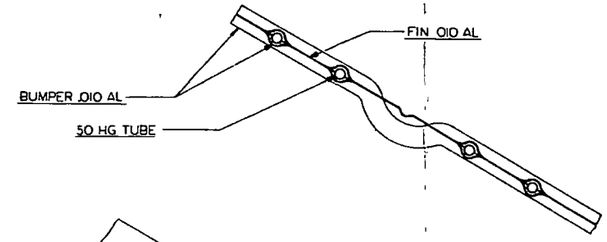
Figure 7



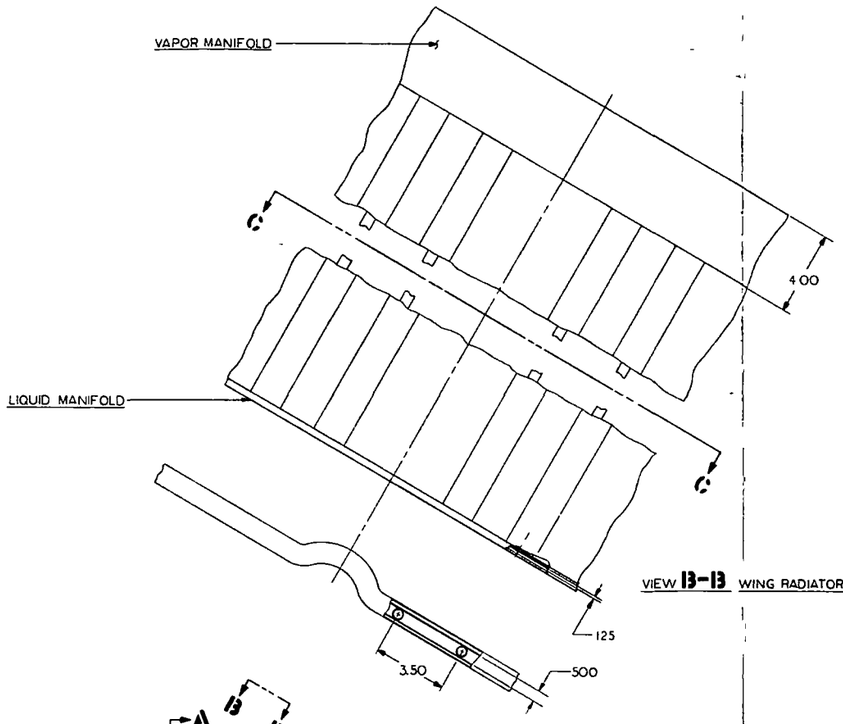
Boiler Temperature-Gradient Characteristics



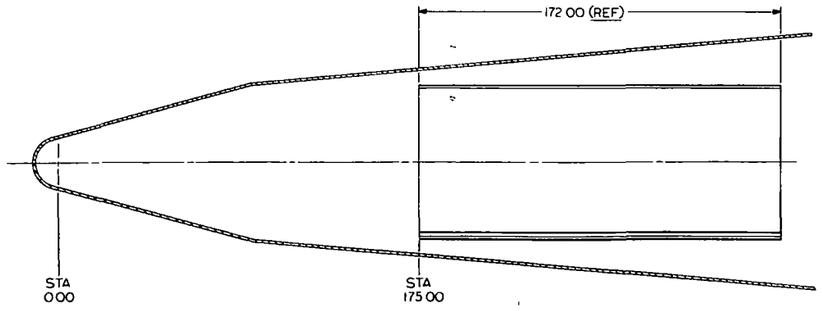
WING RADIATOR UNFOLDED



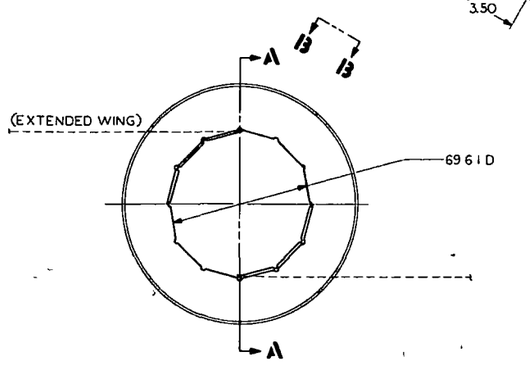
VIEW C-C



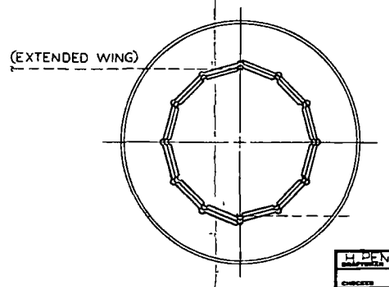
VIEW B-B WING RADIATOR SECTION



SECTION A-A



WING RADIATOR FOLDED UP
30 KW UNIT

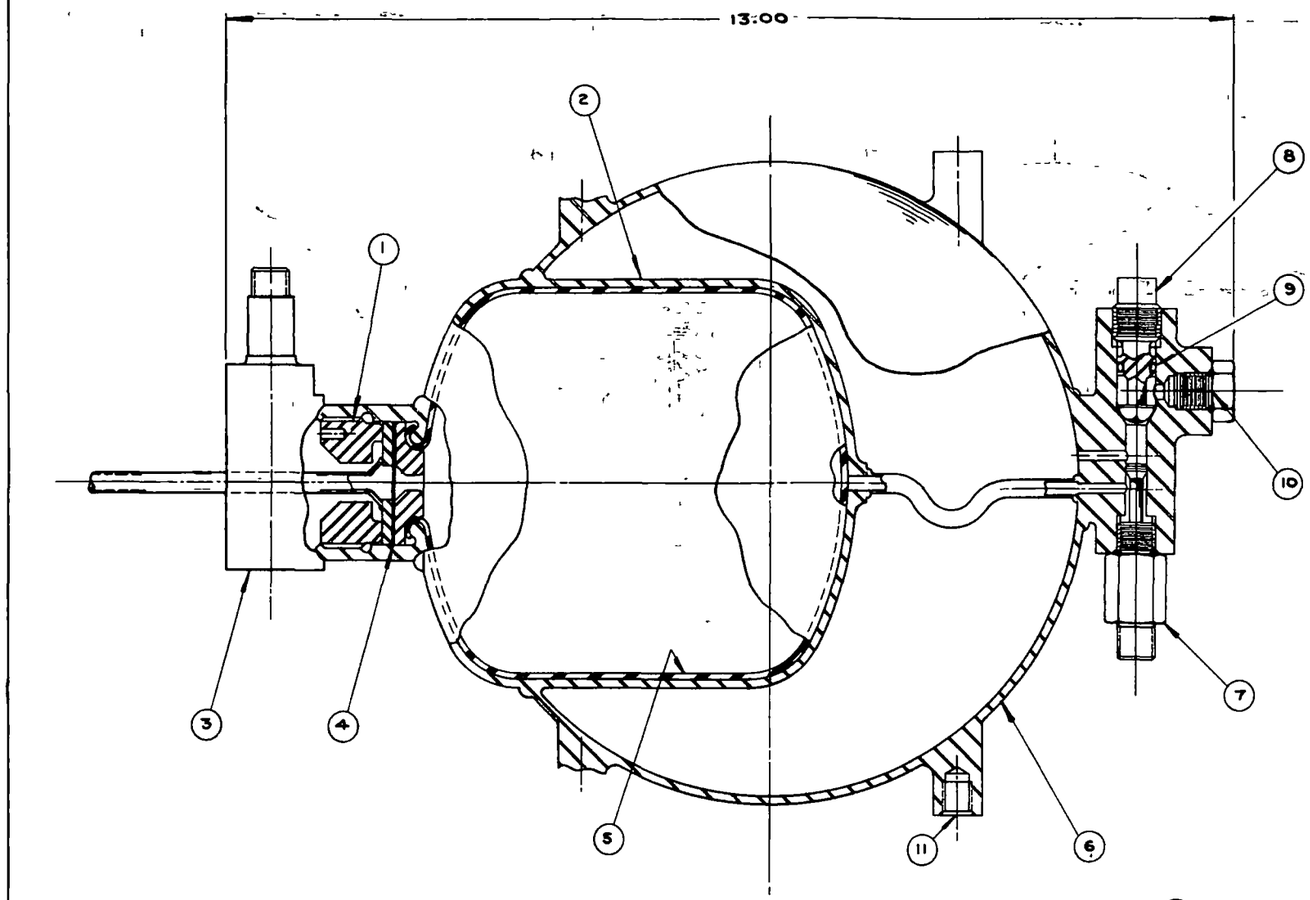


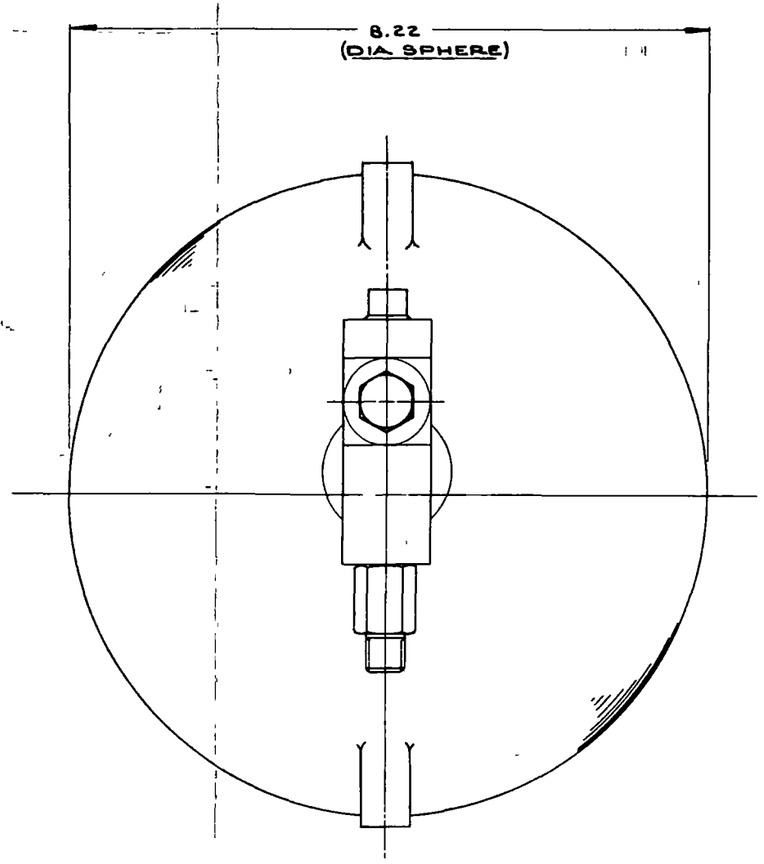
WING RADIATOR FOLDED UP
60 KW UNIT

H. PENNY	12-2-59	RADIATOR ASSEMBLY	TM 90092
P. Edwards	12/15/59		AEROJET-GENERAL CORPORATION AZUSA, CALIFORNIA
		SCALE NTS	CP 060096

Figure 9

~~CONFIDENTIAL~~





1. NUT-RETAINING
2. TANK-MERCURY
3. TUBE CLOSER ASSY
4. DIAPHRAGM ASSY-BURST
5. BLADDER-MERCURY CONTAINER
6. TANK-NITROGEN
7. EXPLOSIVE VALVE
8. VALVE-SEAL
9. O-RING
10. FILL AND PRESSURE CHECK PORT
11. MOUNTING LUGS

DRAWN	12-1-59	RESERVOIR ASSY-MERCURY	TM-90092
CHECKED			AEROJET-GENERAL CORPORATION AZUSA, CALIFORNIA
STRESS			
ENGINEER	12-15-59		
APPROVED	12/15/59		P-060097
PRODUCTION			
CUSTOMER			

Figure 10

~~CONFIDENTIAL~~

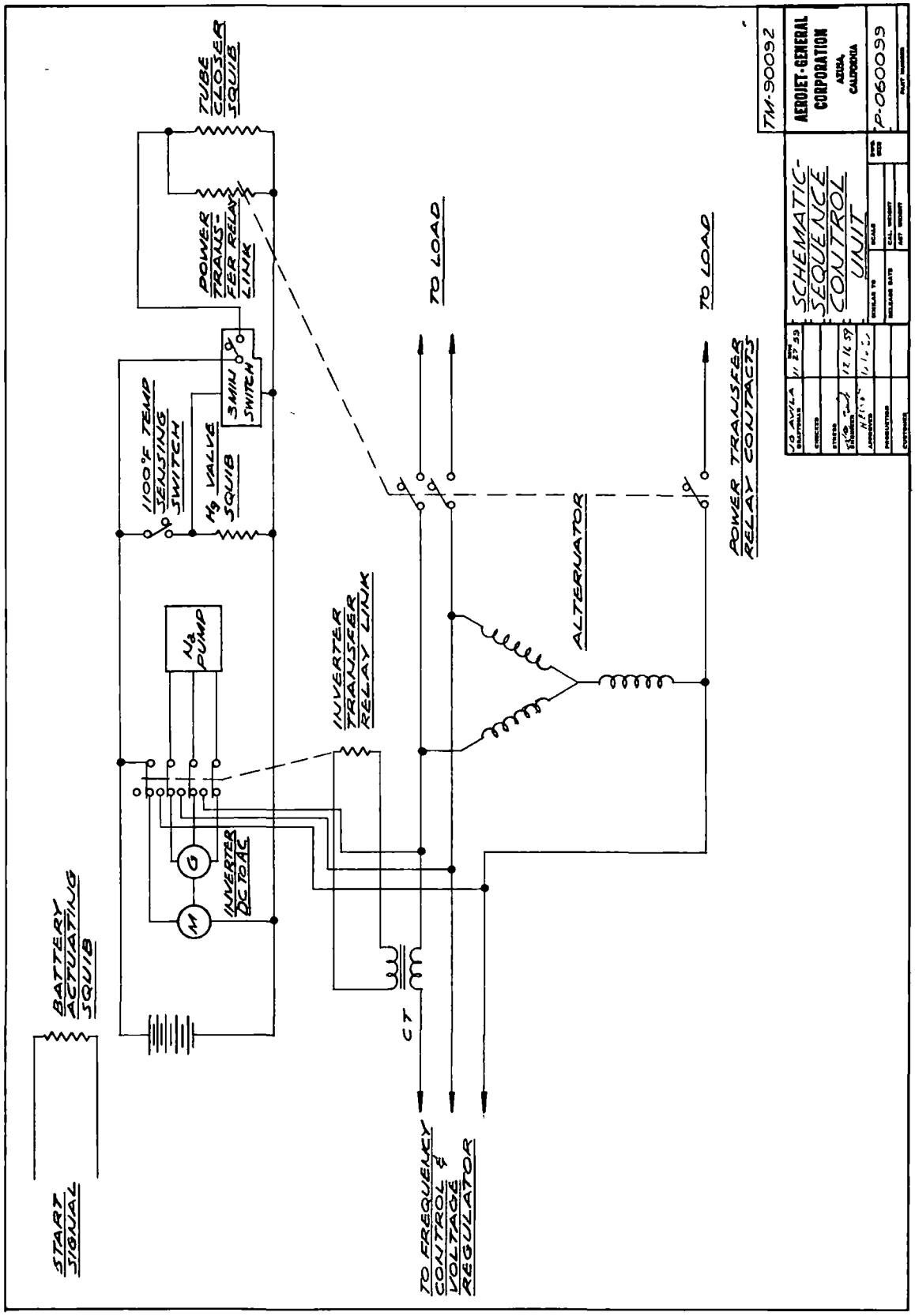

TUBE CLOSER SQUIB
POWER TRANSFER RELAY LINK
1100°F TEMP SENSING SWITCH
SMALL SWITCH
N2 VALVE SQUIB
N2 PUMP
INVERTER DC TO AC
INVERTER TRANSFER RELAY LINK
ALTERNATOR
TO LOAD
TO LOAD
POWER TRANSFER RELAY CONTACTS
BATTERY ACTUATING SQUIB
START SIGNAL
CT
TO FREQUENCY CONTROL & VOLTAGE REGULATOR
SCHEMATIC-SEQUENCE CONTROL UNIT
AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA
TM-90092
P-060099

Figure 11

CONFIDENTIAL

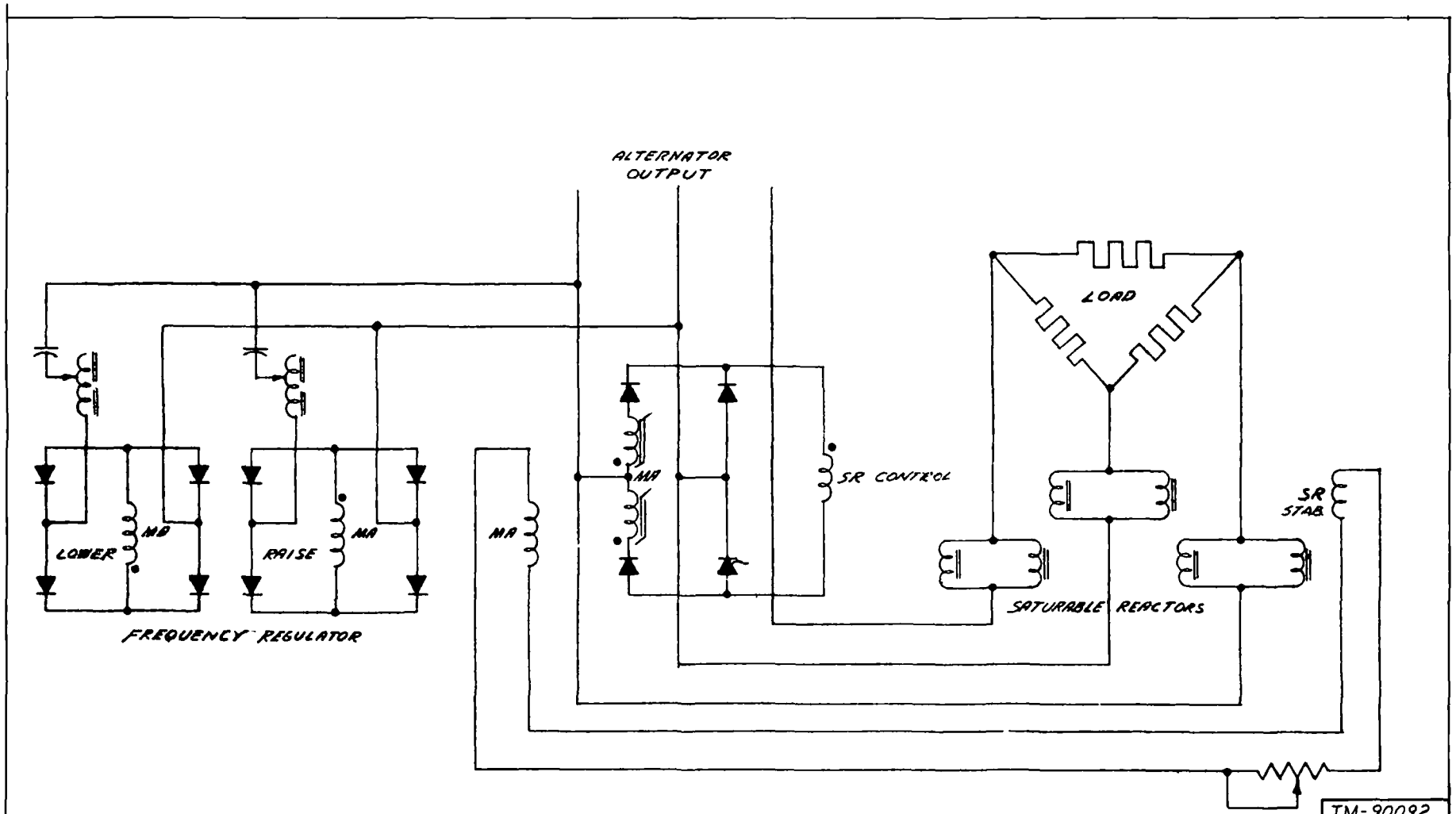


Figure 12

CONFIDENTIAL

AGC-10054A

CONFIDENTIAL

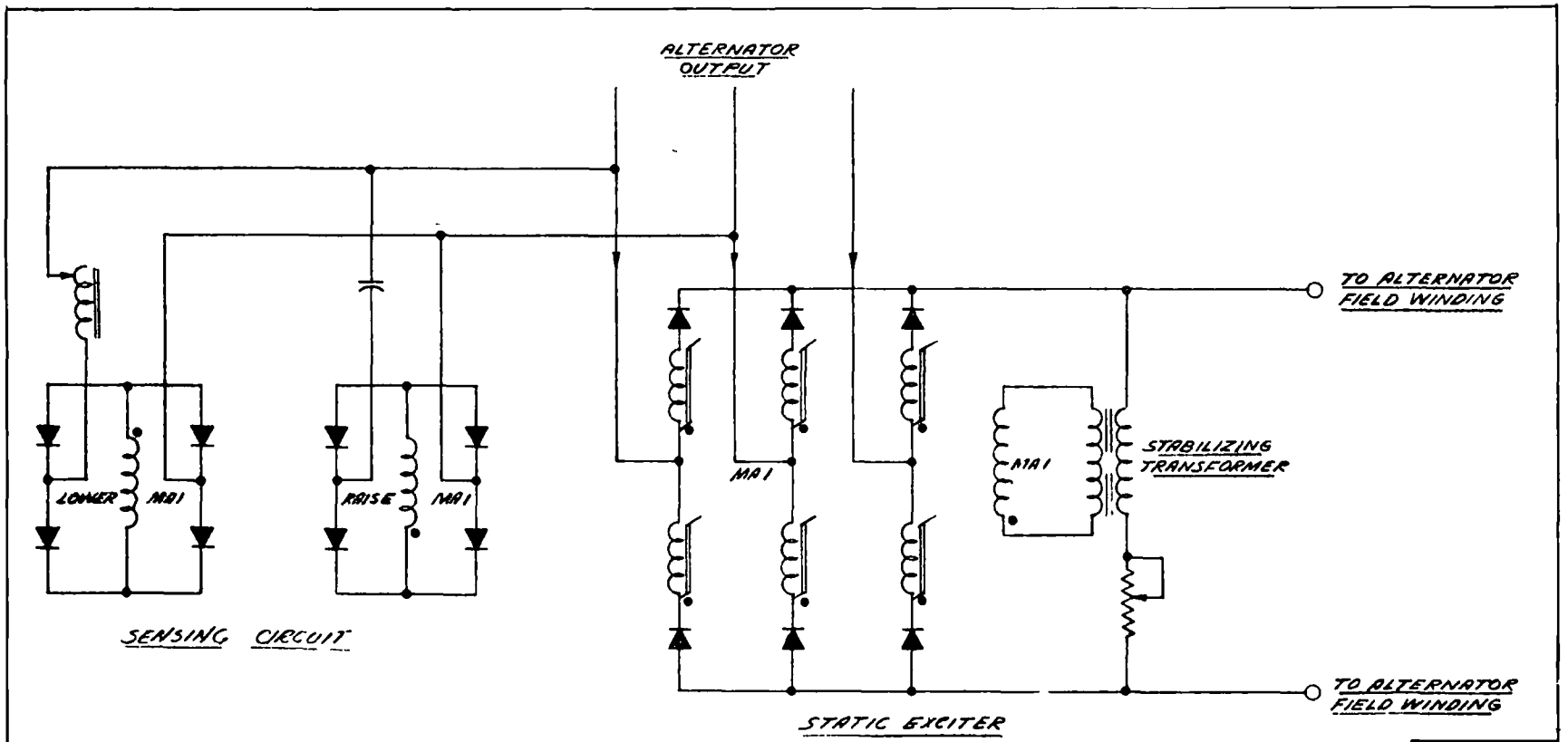
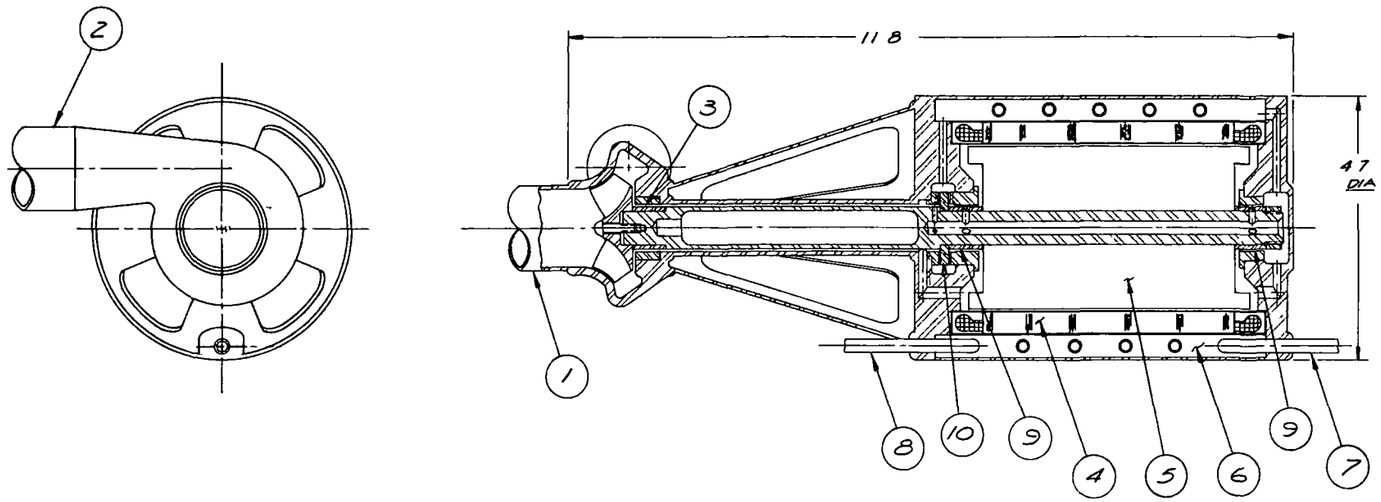


Figure 13

CONFIDENTIAL

AGC-10054A

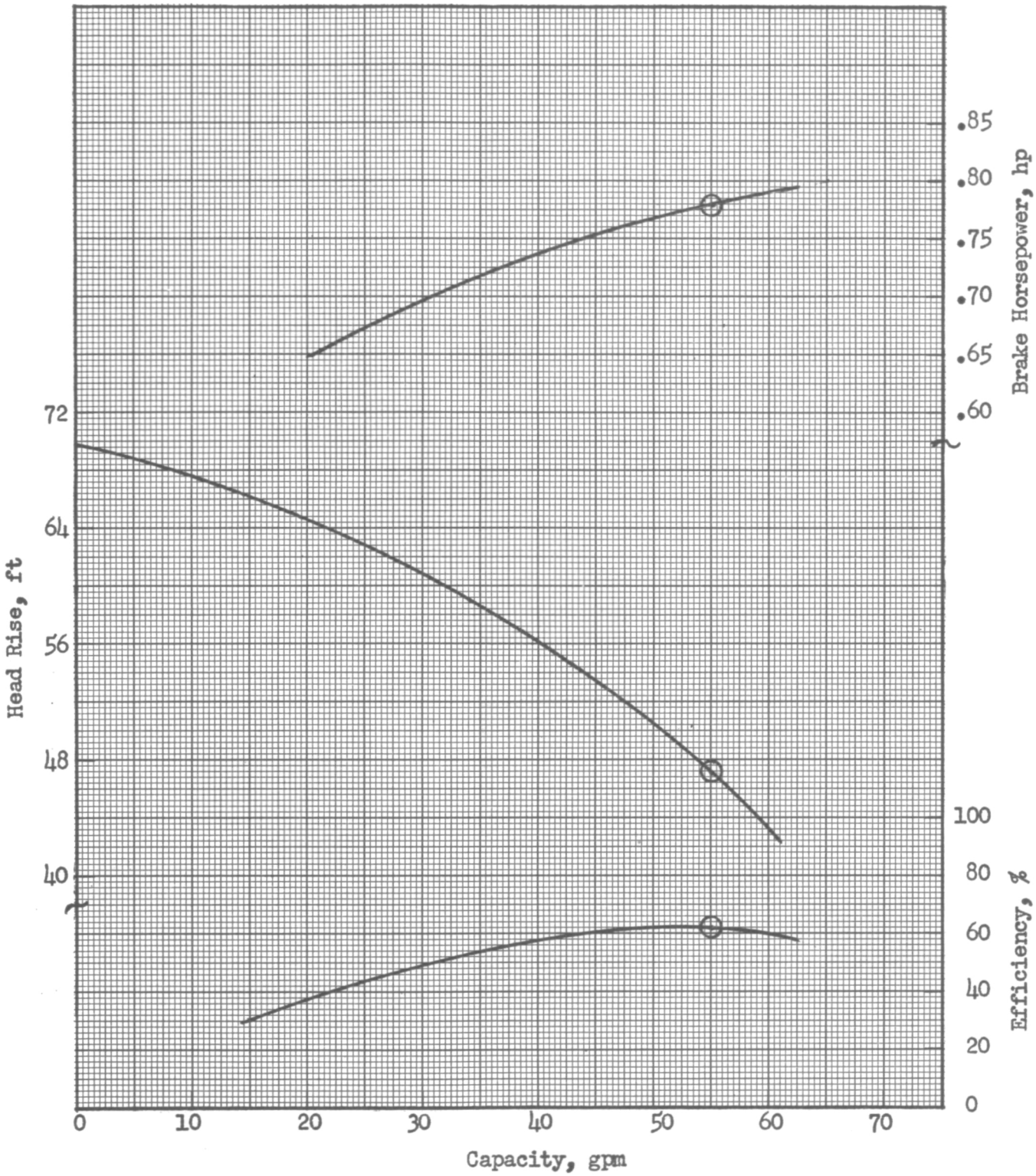


1. PUMP SUCTION
2. PUMP DISCHARGE
3. WEAR RING
4. STATOR
5. ROTOR
6. COOLANT JACKET
7. COOLANT INLET
8. COOLANT OUTLET
9. JOURNAL BEARING
10. THRUST BEARING

J. de Avila	4-28-60	REACTOR COOLANT PUMP ASSEMBLY	AEROJET GENERAL CORPORATION AZUSA, CALIFORNIA
R. Smith	4-28-60	SCALE N.T.S.	SIZE D
			P065888

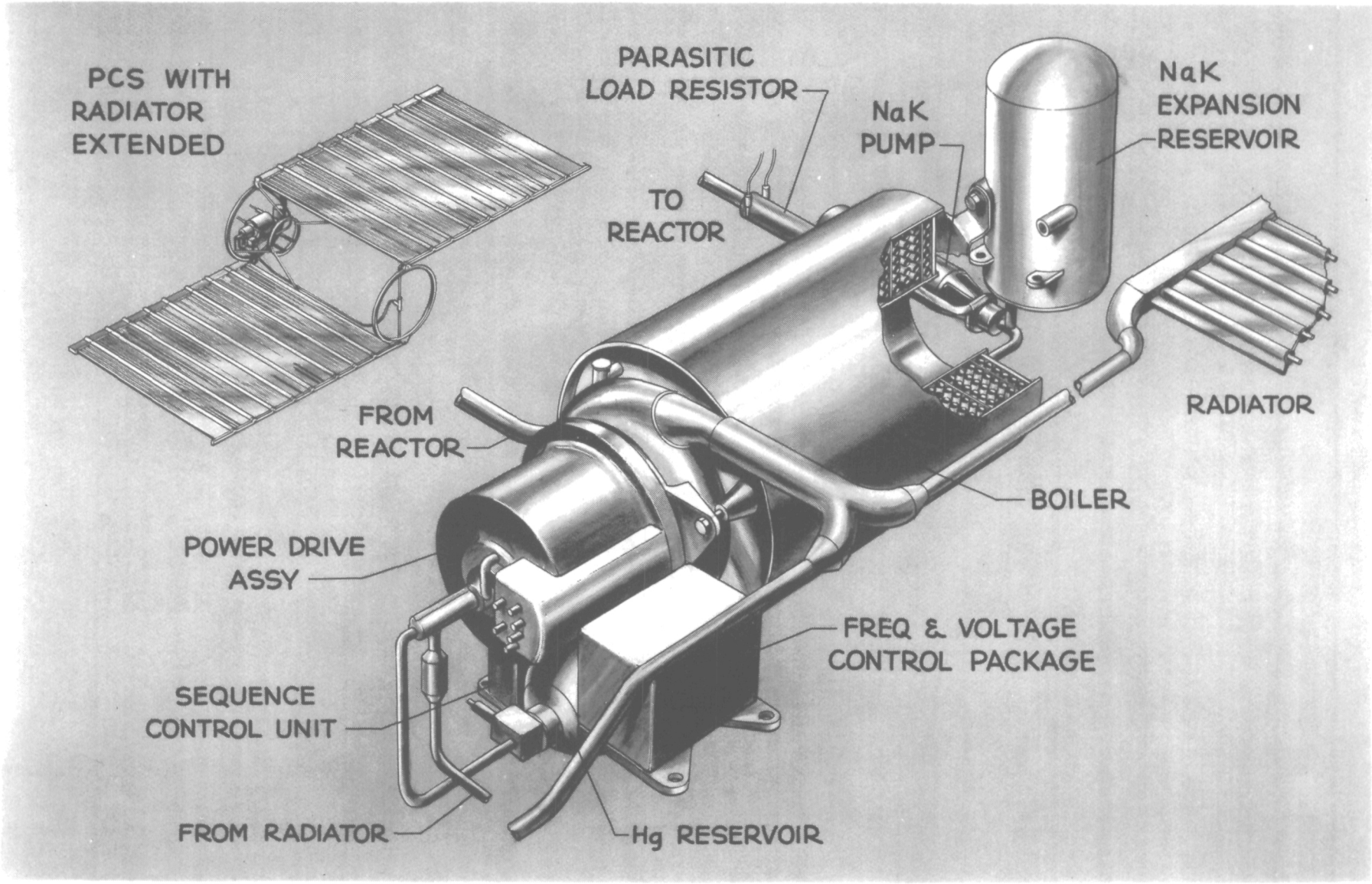
~~CONFIDENTIAL~~

Figure 14



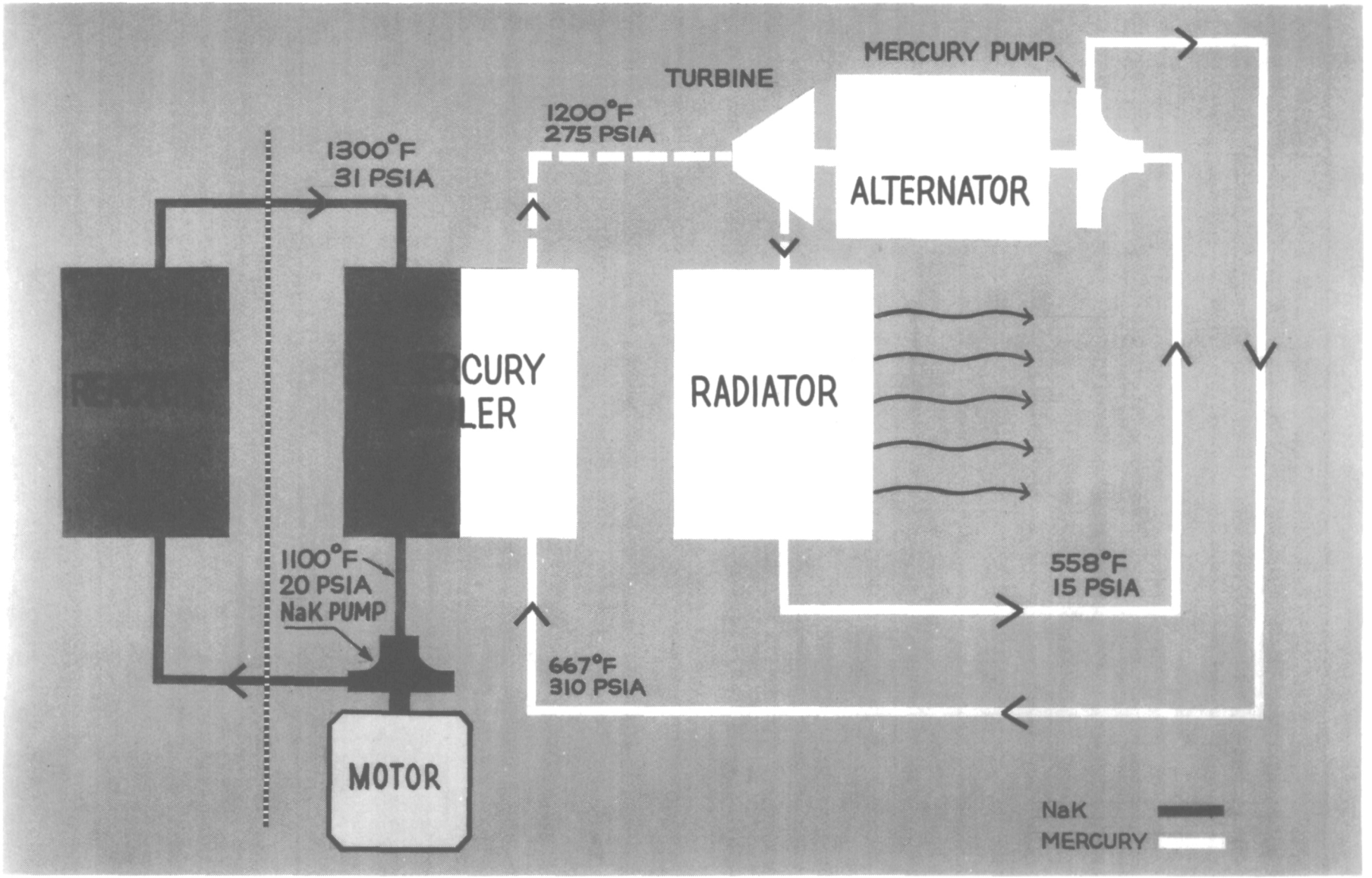
REACTOR COOLANT PUMP PERFORMANCE

SNAP-8 POWER CONVERSION SYSTEM

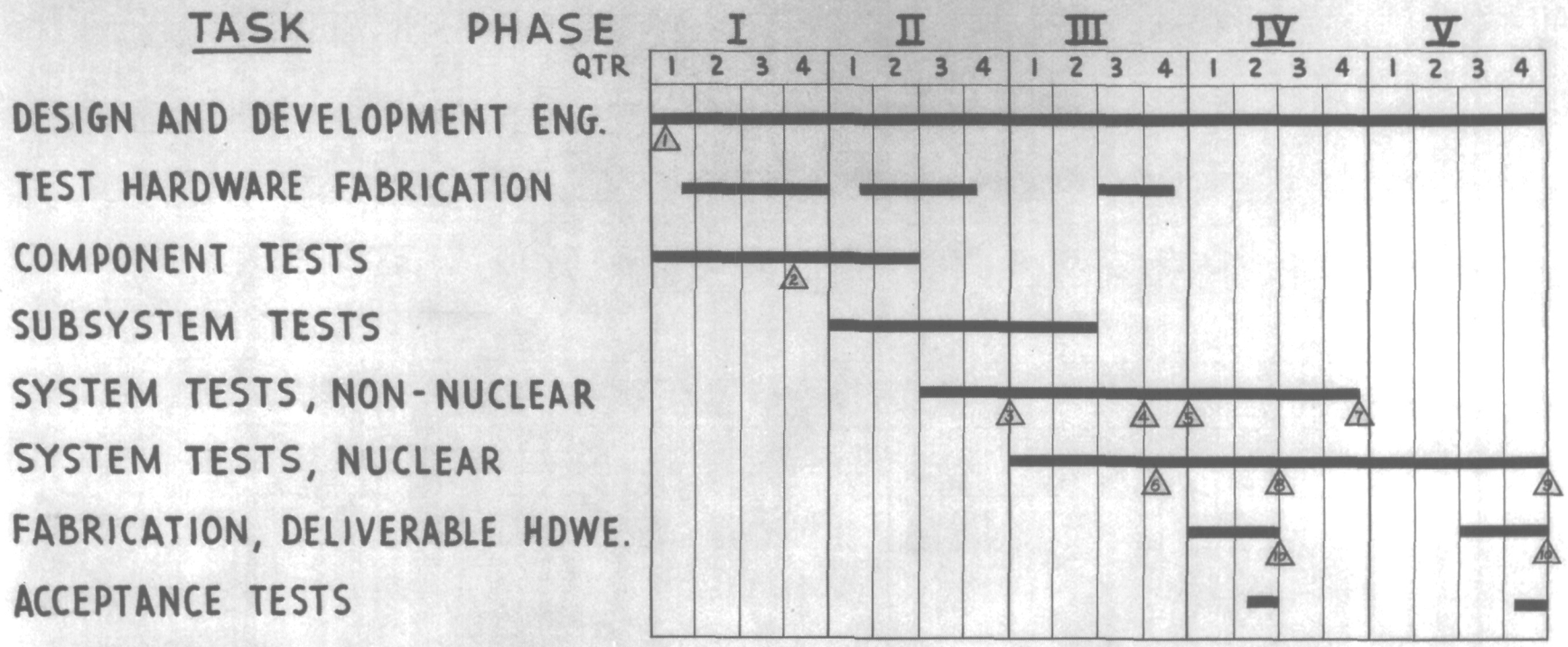


~~CONFIDENTIAL~~

SNAP-8PCS SCHEMATIC DIAGRAM



SNAP-8 PROGRAM SCHEDULE



MILEPOSTS

1. PROGRESS SCHEDULE SUBMITTED
2. COMPLETE INST., COMP. & SUBSYSTEM TEST EQPMT.
3. COMPLETE INST., NON-NUCLEAR TEST EQPMT.
4. COMPLETE 90-DAY LIFE TEST, NON-NUCLEAR (1ST)
5. COMPLETE 90-DAY LIFE TEST, NON-NUCLEAR (2ND)
6. COMPLETE INSTALLATION, NUCLEAR TEST EQPMT.
7. COMPLETE 10,000-HR. LIFE TEST, NON-NUCLEAR
8. COMPLETE 90-DAY LIFE TEST, NUCLEAR
9. COMPLETE 10,000-HR LIFE TEST, NUCLEAR
10. DELIVERY, 2 PCS

SNAP-8 PROGRAM ORGANIZATION